1. Imagine a battery which can be switched off and on at a regular rate, many times per second. When it is "on" it behaves like a regular battery. When it is "off" it has a very small resistance and no emf. Such a device is called a **"square wave generator"**.
   a. Sketch a square wave generator connected to the vertical input of an oscilloscope.
   b. Which oscilloscope terminals must the generator leads connect to? (See page 105.) ___ & ___
   c. Sketch the pattern that you expect to see on the oscilloscope screen if its sweep frequency is roughly one third of the square-wave generator frequency. (You first saw it in page 105.)

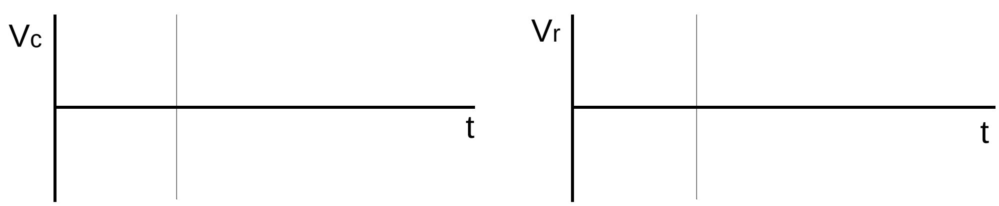
2. Draw a resistor and a capacitor connected in series to a square wave generator. Label the generator.
   a. Show how an oscilloscope can be connected to that circuit to display a graph of *resistor's voltage vs. time*. *Remember that an oscilloscope is just a fancy voltmeter; it has the same connection rule.*
   b. Show how the oscilloscope can be connected to display a graph of the *capacitor* voltage vs. time.
   c. Label the three terminals at the bottom of the oscilloscope with the letters V, G, and H.
   d. Make sure that each diagram shows which oscilloscope terminals are used. (See 1b.)

3. Which of the voltages mentioned in #2 is proportional to current? ____

* 4. How can you use an oscilloscope to make a *current vs. time* graph for that same circuit? (Use #3.)

* 5. How can you use the oscilloscope to make a graph of capacitor *charge vs. time?*

6. Notice that the circuit described in #2 above automatically charges and discharges the capacitor exactly as you did in the capacitor experiment, repeating the process over and over.
   a. When a capacitor is discharging through a resistor the capacitor voltage ___creases.
   b. What sign describes the direction of the capacitor current when it is *discharging?* ____
   c. During the discharging process the magnitude (absolute value) of the resistor voltage ___creases.
   d. The magnitude of the *current* must ___crease while the capacitor is discharging.
   e. Does the discharge process stop suddenly, or does it taper off gradually until interrupted?_____
   f. On the axes below, sketch graphs of capacitor voltage vs. time and resistor voltage vs. time for the discharging process. Stop at the vertical line on each graph. (Use p. 98, 99, and the clues above.)



7. At the time indicated by the fine vertical line, the generator suddenly begins to push electrons back through the resistor to recharge the capacitor, as in # 1. Please answer 7a and 7b with precise *VERBS*:
   a. What *happens* to the direction of the electron flow at that time? ___________
   b. What *happens* to the sign of the resistor voltage at that time? _________ -Does 7a agree? ___
   c. Is that a sudden change? ____ Is the charge conservation law still valid? _____
   d. Is it possible for the charge on a capacitor plate to change suddenly? ____ -Does 7c agree? ___
   e. Must the capacitor's charge vs time graph be continuous? ____
   f. Can the capacitor voltage change suddenly? __ -Must it be continuous?___ Does the sketch agree? __
   g. How are the three voltages in this circuit related? ____ = _________ (See #5 on RS IX.)
   h. Let the generator continue switching on and off like a square wave generator. Use your knowlege of capacitors and the hints above to fill in the sections to the right of the fine vertical lines on the graphs as you did on pages 98 and 99. Show two full cycles. Save copies of these sketches for page 107.

8. In the capacitor experiment on page 98 did you ever find any voltage that *grows* exponentially, like money in a savings account?____ *If so, please name it.* --Did all of the voltage vs time graphs have horizontal asymptotes?____ *If not, name the exceptions.* --Were any of the voltages in that experiment ever too great to measure?____ --Did any segment of any curve on those graphs have an infinite slope?____ --Do the sketches you made for #6 and 7 agree with these facts?____

9. After your sketches and plans have been approved, hook up the circuit described in #2 and play with it. Are all of the peaks on the V_r vs t graph equidistant from the time axis?___ -Do your sketches agree?____ -Are there any discontinuities in the Vc vs t graph? ___ Do 7e, 7f, & 7h agree? __

1. Make a large and reasonably accurate sketch of the V_r vs time graph that you made in 6 & 7 on p. 106.
   a. Copy the definition of "half-life" from RS XI beside the sketch, and *use it in 1b.*
   b. Indicate the half-life on your sketch, as you did on page 103. Label it clearly.
   c. Assuming that the magic transitions (vertical lines) occur at one-second intervals, estimate the half-life indicated on your sketched graph. Write that numerical estimate (with units) near your sketch.
   d. Exactly how is the generator's period related to its frequency? P = ___ (See RS I, RS VII, or RS VIII.)
   e. Indicate the period of the generator on your V_r vs. time graph. Label it clearly.
   f. The generator's "half-period" is just half of its period. Indicate the half-period clearly on your graph.
   g. Using 1c, give the numerical value and units of that half-period.

* 2. Suppose we adjust the generator frequency to make the half-period *equal* to the half-life of the circuit. *Use the instructions below* to make careful sketches of the resulting graphs of V_r vs. time and V_c vs. time. Label each graph so I can see which voltage it describes.
   a. Sketch graphs of V_r vs. time and V_c vs. time for the discharging process, as on 98, 99, & 106.
   b. Make a dot on each curve at the point where the process is half-completed. *Erase* to the right of it.
   c. Let the magic battery switch "on" at the time of that halfway mark. Using the graphs that you made for the charging capacitor in #3 on page 98, sketch segments to the right of the dot on each graph.
   d. Label *each* segment on *each* graph as "charging" or "discharging". (See 6a & 6b on p. 106.)
   e. Let the charging process be interrupted after exactly one half-life. At that time the magic battery switches *off*, causing the capacitor to begin ________ing again. Let your graphs show *several identical cycles* of this off-on process. The _______ vs time graph must be *continuous*, as on p. 106.
   f. Do all the segments in your sketched graphs have equal widths? ____ -Are all of the peaks on the voltage-time graph equidistant from the "t" axis, as in #9 on page 107? ___ (If not, please *fix* them.)
   g. The definition of "half-life" says if the peaks are each two blocks from the axis then the other ends of the arcs must be just ____ block from the axis. Do your sketches show that clearly? ___
   h. Are those "blocks" clearly visible and *square* in 1b *&* #2, as they are on the oscilloscope screen? ___
   i. During any interval in which the value of an exponential function changes by a factor of 2, the slope must change by a factor of ___. (That's a characteristic property of ___________ curves, mentioned in 5g on page 102.) Do your sketches illustrate that property? ___
   j. Do your sketches agree with #7 & 8 on page 106? __ -Have you made all necessary corrections? ____

3. In #2 you saw what happens to the graphs if we reduce the generator period. Now let's reduce it more:
   a. Use the same kind of reasoning as in #2 to predict the shapes of the graphs if the generator is adjusted to make its half-period *much less* than the half-life of the circuit.
   b. A short segment of any curve must look like a ________ line even if it is magnified. The sketches in 3a should show that clearly. -Do they? ___ -Which graph *must* be continuous? _______
   c. Let "ΔV" represent the change in voltage that occurs during one segment on the V_r vs. t graph in #2 *or* #3. Let "V_o" represent the voltage at the beginning of such a segment. Use those symbols to label your graphs. According to the instructions, the ratio $\Delta V/V_o$ must be equal to ___ in #2, and must be _____ than that amount in #3. *If your sketches do not show that fact clearly, please repair them.*

* 4. After your plans and predictions have been approved ask for a resistor between 1K and 100K and a capacitor between 0.01 and 0.1 μF. Hook up the circuit and see if your predictions are correct.
   a. Adjust the generator to make its half-period *equal* to the half-life of the circuit, as in #2. Record the resistance and the generator frequency. *Also record the uncertainties or SDC's of those quantities.*
   b. Show how that frequency is used to calculate the generator's period and half-period. *Don't forget to calculate the uncertainties of the results.* Use scientific notation and SI units. (See #1d.)

* 5. The SI unit for the product of R and C is ______. That's why RC is called a "**time constan**t". In #12 on RS XI you recorded an equation relating the half-life of this kind of circuit to its time constant.
   a. Copy that equation from #12 RS XI. *Use a letter to represent the proportionality constant.*
   b. What can you say about the units of that constant if all three variables are in SI?
   c. Copy the *best* available value for that constant from RS XI. Also copy its estimated uncertainty.
   d. Solve equation 5a algebraically for the unknown capacitance.
   e. Use the data recorded in #4 to calculate the unknown capacitance in SI units. Show how your result (including units and uncertainty) is obtained. Remember to use scientific notation if appropriate.
   f. Identify the main source of uncertainty in that calculation. Explain your choice. Also explain why it was not practical to make that measurement more precise.
   g. Summarize your method for measuring "C" on the back of RS XII. *You will need it for page 111.*